

# ASSESSMENT OF NEW ACTIVE SAFETY SYSTEMS ADDRESSING URBAN INTERSECTION SCENARIOS INCLUDING VULNERABLE ROAD USERS

**Julia Bräutigam**

Federal Highway research institute (BASt), Brüderstraße 53, 51427 Bergisch Gladbach, Germany

**Alvaro Esquer**

Applus+ IDIADA, Santa Oliva, 43710, L'Albarnar, Tarragona, Spain

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## ABSTRACT

Bicyclists and pedestrians belong to the most endangered groups in urban traffic. The EU-funded collaborative research project PROSPECT ('PROactive Safety for PEdestrians and CyclisTs') aims to significantly improve safety of those unprotected traffic participants by expanding the scope of scenarios covered by future active safety systems in passenger cars. Concepts for sensor control systems are built into three prototypes covering emergency interventions such as Autonomous Emergency Braking (AEB) as well as Autonomous Emergency Steering (AES). These systems tackle the well-known challenges of currently available systems including limited field-of-view by sensors, fuzzy path prediction, unreliable intent reaction times and slow reaction times. These highly innovative functions call for extensive validation methodologies based on already established consumer testing procedures. Since these functions are developed towards the prevention of intersection accidents in urban areas, a key aspect of the advanced testing methodology is the valid approximation of naturalistic trajectories using driving robots. Eventually, several simulator studies complemented a user acceptance and benefit analysis to evaluate the expected overall impact of the PROSPECT systems.

The results achieved within the PROSPECT project are highly relevant for upcoming test protocols regarding the most critical situations with Vulnerable Road Users (VRU). With introducing the new methods in Euro NCAP (European New Car Assessment Programme) a significant increase in road safety is expected.

## INTRODUCTION

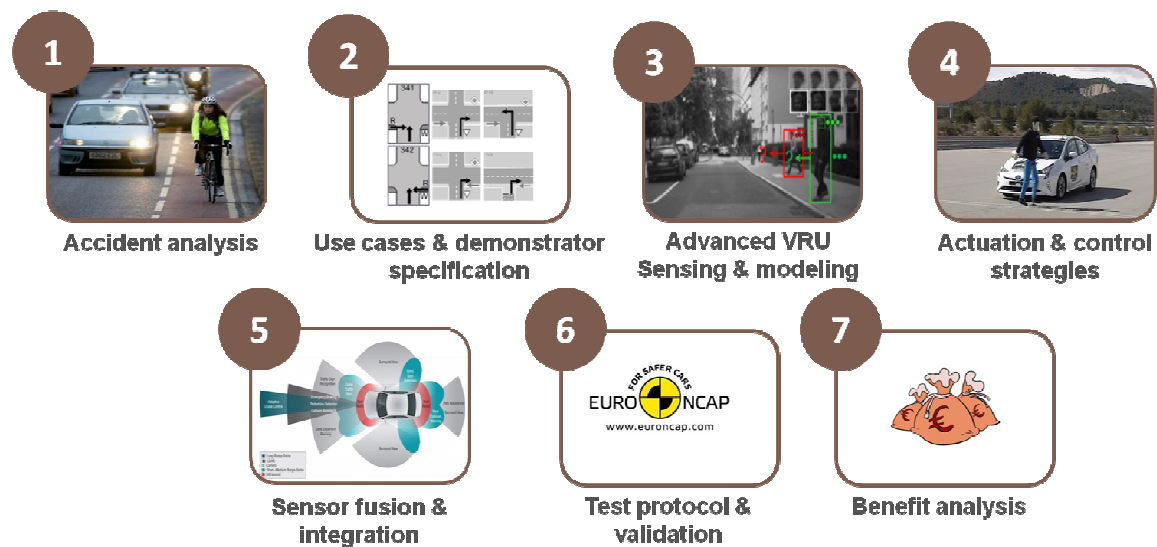
Accidents involving bicyclists and pedestrians remain a significant issue for road safety, accounting for more than 25% of road fatalities in the European Union [1]. This value stresses the importance to take measures aimed to reduce the number of occurring fatalities with vulnerable road users (VRU) significantly. The corresponding intention of the European Union planning to move close to zero fatalities in road transport by 2050 is already stated in the white paper (Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport systems), which was published in 2011[2].

To meet these ambitious goals, Advanced Driver Assistance Systems (ADAS) are a promising option to focus on active safety systems addressing VRU safety. Autonomous Emergency Braking systems (AEB) are already established in state-of-the-art consumer testing [3]. Consumer test organizations such as Euro NCAP (European New Car Assessment Programme) have a high impact on vehicle safety by introducing transparent safety requirements and accompanying test procedures. Consumer testing is considered to be an important part of vehicle safety, therefore PROSPECT ('PROactive Safety for PEdestrians and CyclisTs') will supply test procedure proposals to Euro NCAP (the dominant vehicle consumer testing organization in the EU-28) starting in 2020.

PROSPECT is a collaborative research project funded by the European Commission. The project pursues an integrated approach comprising in-depth and multiple European accidents studies involving VRUs, combined with results from urban naturalistic observation. Real intersections throughout Europe were monitored to understand critical situations that occur between vehicles and VRUs. The gained knowledge from these observations is used to identify crucial factors leading to conflict situations and to better anticipate accidents. As the output, the most relevant accident scenarios are identified for pedestrians and cyclists focusing on urban environments, where the majority of accidents involving VRU occur. Further on, generic use cases were derived as basis for the development of test scenarios for the ADAS systems. Proposed test cases derived from the accident data as well provide a description of how to reproduce a specific use case on closed test tracks.

The accident analysis represents a key input for the system specifications for development of the three project prototype vehicles. These demo-vehicles are extensively tested in more realistic scenarios. PROSPECT's broad testing methodology goes beyond what is currently used in consumer testing, such as turning in intersection scenarios based on naturalistic driving observations in real traffic throughout Europe. The concept for more realistic testing includes intersection markings which allow the efficient testing of all test cases, mobile and light obstruction elements and realistic surroundings like traffic signs or lights. Eventually, the testing results from

the prototype evaluation as well as several simulator studies build the basis for an over benefit analysis assessing the socio-economic benefit of the developed functions. The PROSPECT methodical approach is presented below in *Figure 1*.



**Figure 1: PROSPECT methodology**

The findings within PROSPECT contribute not only to the state-of-the-art knowledge of VRU-vehicle behavior, but to technical innovations, i.e. assessment methodologies and tools for testing of next generation VRU active safety systems, as well. In terms of the estimated impact, the introduction of a new level of safety systems in the market will enhance VRU road safety in the 2020-2025 timeframe, contributing to the ‘vision zero’ objective of no fatalities or serious injuries in road traffic set out in the Transport White paper. Test methodologies and tools are considered for 2022-2024 Euro NCAP road-maps.

This paper will focus on the test protocol and prototype evaluation that was conducted within the PROSPECT project. Initially, the derivation of test cases based on the accidentology is explained followed test protocol development. Eventually, the assessment of the prototype is exemplarily explained. In the discussion section, the findings and limitations are summarized and an outlook is given.

#### **From Accident Analysis over use cases to test cases**

The first stage of the project included macro statistical and in-depth accident studies targeting VRU accidents in urban traffic. The studies were performed in Europe focused specifically on pedestrians and cyclists. An overview and an in-depth understanding of the characteristics of road traffic crashes involving vehicles and VRUs (i.e. pedestrians, cyclists, riders of motorcycles, e-bikes and scooters) was provided for different European countries. Early investigations have shown that the crashes between passenger cars and pedestrians or cyclists are the most relevant in Europe. *Figure 2* shows a summary of the most relevant accident scenarios related to car-to-cyclist crashes that were extracted from this study.

The in-depth understanding of the crashes includes the identification of the most relevant road traffic accident scenarios and levels of injury severity sustained, as well as the transport modes that represent a higher risk for VRUs. Besides extensive literature studies, comprehensive data analyses have been performed featuring information from recent years. From the most relevant accident scenarios, detailed car-to-cyclist crash analyses have been performed focusing on the causation of crashes: car-to-cyclist accidents have been analyzed from the car driver’s point of view. With this approach deeper insight can be gained about situations faced by the drivers especially why they sometimes failed to manage these crash situations [4].

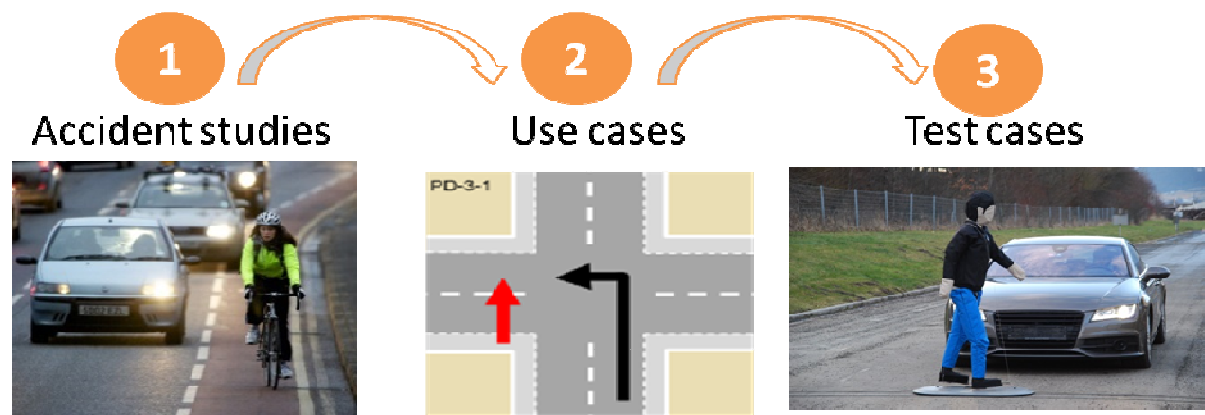
Accident type	UTYP Pictogram	PROSPECT pictogram (basic version)
(I) Car straight on, cyclist from near-side		
(II) Car straight on, cyclist from far-side		
(III) Car turns		
(IV) Car and cyclist in longitudinal traffic		
(V) Others		

**Figure 2: Overview of most relevant accident scenarios between passenger cars and bicyclists.**

The accident scenarios obtained from the studies describe the type of road users involved in the accident, their motions (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as accident types and further contextual factors, like the course of the road, light conditions, weather condition and view obstruction. More information is available on the project deliverable “Accident analysis, Naturalistic Driving studies and Project implications” [5].

The most relevant accident scenarios have been clustered in use case or target scenarios addressed by the project. These use cases contain less detailed information and are used to derive the sensor specifications of the prototypes including information, such as stereo vision base line, image resolutions, microwave radar sensitivity/accuracy or the necessary field of view of the corresponding sensor. Additionally, issues related to sensor processing required by the chosen scenarios including VRU detection areas, correct vs. false recognition rates, localization accuracy and computational latencies had to be taken into account. Since the safety systems developed within PROSPECT are relying on video and radar based technology constantly surveying the surroundings of the vehicle by an extended field of view, more complex scenarios can be addressed than currently state-of-the-art systems are capable of. Specific information on the configured and evaluated prototypes is available in the related PROSPECT deliverable [6].

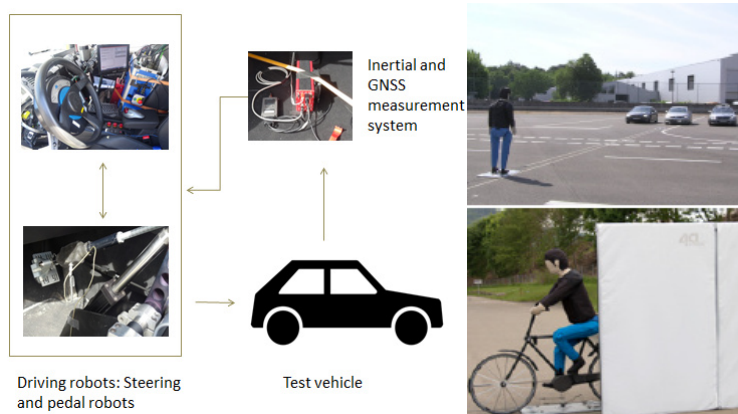
The final goal was to define representative Test cases from available Use Cases, taking into account relevant parameters and representative values for the selected parameters based on accident potential and system analysis. Constraints taken into account are a limited and feasible number of test runs, durability (e.g. maximum impact speed) and the feasibility of the test tools (see *Figure 3*).



**Figure 3: From accident analysis to test cases - scheme**

## TEST PROTOCOLS

For the benefit assessment of the prototype vehicle's functionality a testing methodology is required that goes beyond what has currently been used in European consumer testing (Euro NCAP). While under evaluation, the Vehicle Under Test (VUT) has to be equipped with driving robots, including a steering and pedal system as well as a DGPS measurement system, to keep each individual test repeatable and comparable between vehicles. This equipment ensures a reproducible path for the VUT with a lateral tolerance of less than 5 centimeters (see *Figure 4*, left). In PROSPECT the crash opponent is a VRU dummy on a self driving platform which is time-synchronized with the VUT. In *Figure 4* the test tools are displayed. In various accidents that had been analyzed for the use case definition, the VRU was significantly often hidden by obstructive element. Bringing a solid obstruction element into consumer testing, the test are becoming more and more advanced for the safety systems to fully avoid impacts (see *Figure 4*, left below).

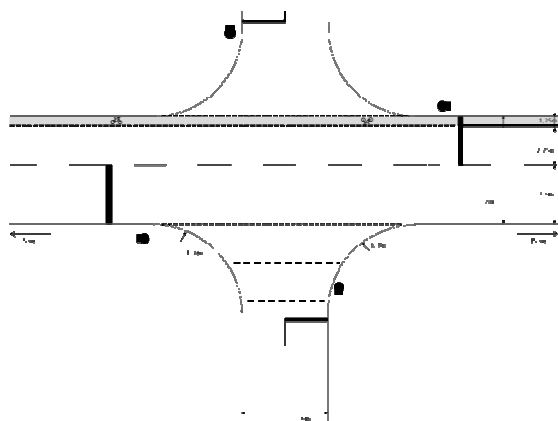


**Figure 4: VUT testing equipment (left); Pedestrian and bicycle dummy with obstruction (right)**

In the following the main two adaptations regarding the introduction of a basic intersection layout and the use of naturalistic trajectories reproduced by using driving robots are explained.

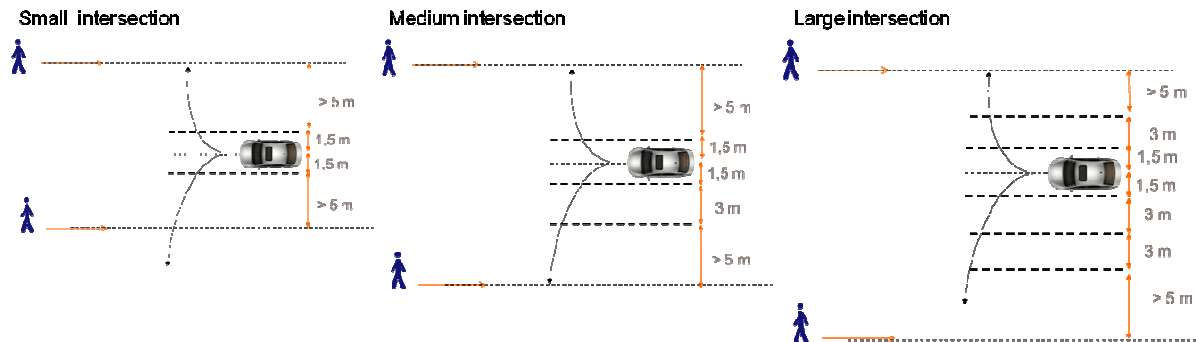
### Intersection design

Intersections and the possibilities for different drivers to turn in these intersections are various. Defining a specific layout where all addressed scenarios could be tested is the initial step to limit the options for turning scenarios on the one hand and on the other hand, it already prepares the testing procedure for more advanced technologies that would be able to take the intersection boundaries into account for the decision on their behavior. The proposed intersection in PROSPECT (see *Figure 5*) is based on German recommendations for road construction for urban environmental intersections [7]. The intersection layout allows a cornering radius ranging from 8 – 15 meters. Aligning this with the information from the detailed accident analyses that measure the impact speeds in urban intersection accident scenario in a range from 10 to 25 kph will result in estimated lateral accelerations below  $3 \text{ m/s}^2$ .



**Figure 5: Intersection layout proposed by PROSPECT**

The advantage of that simple intersection design is that depending on the future test cases at hand and the intention of the potential test, the suggested intersection layout can be easily adapted to a bigger size. PROSPECT proposed a small intersection as a start for future VRU test cases, but depending on increased driving speed and the desired trajectory it might be of interest to set up a medium to large intersection. In *Figure 6* the idea for designing custom intersections for oncoming scenarios is shown.

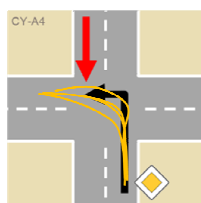


**Figure 6: Different intersection sizes depending on the test design.**

### Trajectories

For the analysis of realistic driving behaviour, naturalistic driving studies (NDS) were conducted to observe the behaviour of different driver in different countries throughout Europe. Unfortunately, real intersection layouts highly vary regarding basic parameters such as lane width and the angle between the two crossing streets. Of course, strong variations can be found in other characteristics, especially regarding the environmental features. In urban areas buildings, parked cars or trees often block the free view over the approaching street arm. Additionally, surrounding traffic, for example oncoming cars, alters the chosen trajectory and speed profiles to a not negligible extent. As a result, the collected data shows a wide range of possibilities how to negotiate many variants of different intersections.

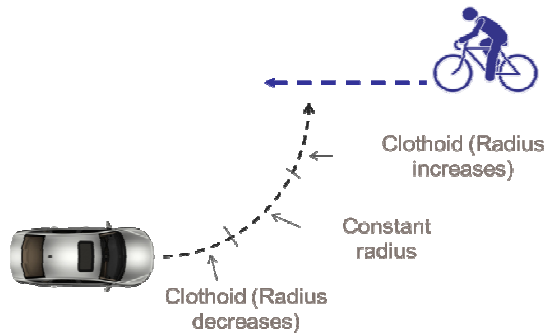
As mentioned above, consumer testing scenarios require a high repeatability ensuring a sufficient comparability of the results. Moreover, any additional test scenario is under strong boundaries regarding a reasonable time and money frame for the executing test laboratories. Therefore, the aim for generating feasible trajectories on closed test tracks is to simplify out of the whole range of possible real turning scenarios into one or a few signature trajectories representing the data found in the naturalistic driving studies and accident analyses as best as possible. As can be seen in *Figure 7*, restricting the intersection geometry stills leads to various possible trajectories.



**Figure 7: Possible trajectories for a given intersection layout depending on various factors, including obstructions, traffic, and driver condition.**

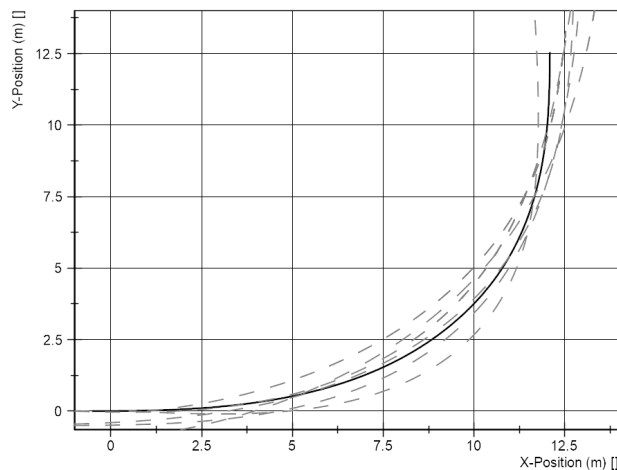
Nevertheless, a detailed analysis of the available data shows that despite the differences in highest curvature, start and end position of the vehicle, the overall process of negotiation a turn is similar almost every time and can be split into three sections (see *Figure 8*) consisting of two clothoids and a constant radius.

- Section 1      Linear increase of the curvature, corresponding to curve entry
- Section 2      Constant radius cornering
- Section 3      Linear decrease of the curvature, corresponding to the curve exit



**Figure 8: schematic description of the cornering sections**

There is a tendency for the last section to be longer than the prior sections in the data from the naturalistic driving studies. This turned out to be of difficulty for the testing equipment on the test track. To be able to ensure tight tolerances over a wide variety of Vehicles under Test (VUT), the sections were split equally with a length distribution of 1/3 each. In *Figure 9* the derived trajectory based on the naturalistic driving data, accident analysis and testing experience is shown in *Figure 9* (solid line). The dashed lines represent selected trajectories from the naturalistic driving studies for one specific intersection close to the layout chosen in the project.



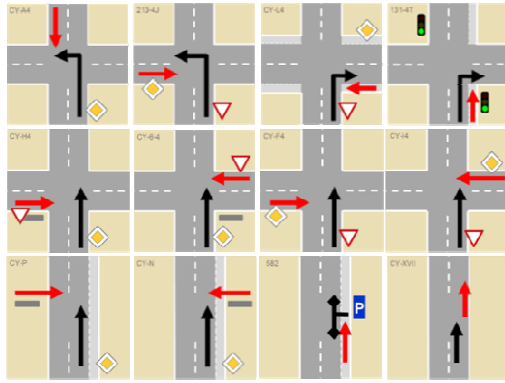
**Figure 9: PROSPECT trajectory (solid) overlaid with selected naturalistic driving trajectories**

The selected trajectory is a compromise between manifold possibilities provided by human driver behaviour and a repeatable and easy-to-use trajectory on the test track.

## EVALUATION OF PROTOTYPES

The vehicle-based functional tests have been carried out in 2017 and 2018. Initially some of the PROSPECT use cases were reproduced in proving grounds with four production vehicles equipped with state-of-the-art active safety systems respecting VRU protection. These baseline systems are able to identify pedestrians and bicyclists and if necessary react in dangerous situations. With respect to current consumer test programmes these reference cars have achieved the highest qualification. These preliminary tests allowed obtaining the baseline performance of current AEB systems applied to VRU. The vehicles were treated anonymously when releasing the results, because only the average performance of market vehicles is of interest. Moreover, the reference testing helped to define the methodology and test procedures that were later used to evaluate the three prototype functions developed in the project.

Scenarios involving bicyclists are generally more challenging for the safety systems as they travel faster than pedestrians. Functions need to process and identify hazard situations as quick as possible to activate the automatic braking or steering application and avoid the crash. Therefore, only the longitudinal test case (bottom right in *Figure 10*) is additionally conducted with a pedestrian dummy. The velocity of the bicyclist is 15 km/h, for the pedestrian the velocity is set to 5 km/h. All scheduled test cases are displayed in *Figure 10*.



**Figure 10: Assigned prototype test cases**

The top row of the figure contains all intersection scenarios where a turning trajectory is required. In the middle row and the two left cases of the bottom row of the figure, crossing scenarios are shown. The second to last scenario describes a parking test case. The VUT is parked and the bicycle dummy is coming from the back. The test engineer opens the door when the dummy is close to the vehicle. The last scenario on the bottom right of the figure is the longitudinal test case. This scenario was conducted with more than one prototype and with different parameters regarding the placement of the VRU-dummy and the autonomous vehicle intervention. The basic setup of this scenario was conducted with 25% and 50% offset between VRU und VUT. For higher speeds ranging from 50 to 60 km/h, one prototype showed an ESP-induced emergency steering manoeuvre, while another prototype vehicle applied some torque on the steering wheel for the evasive manoeuvre. The dummy was placed to the very right side of the lane for this specific case.

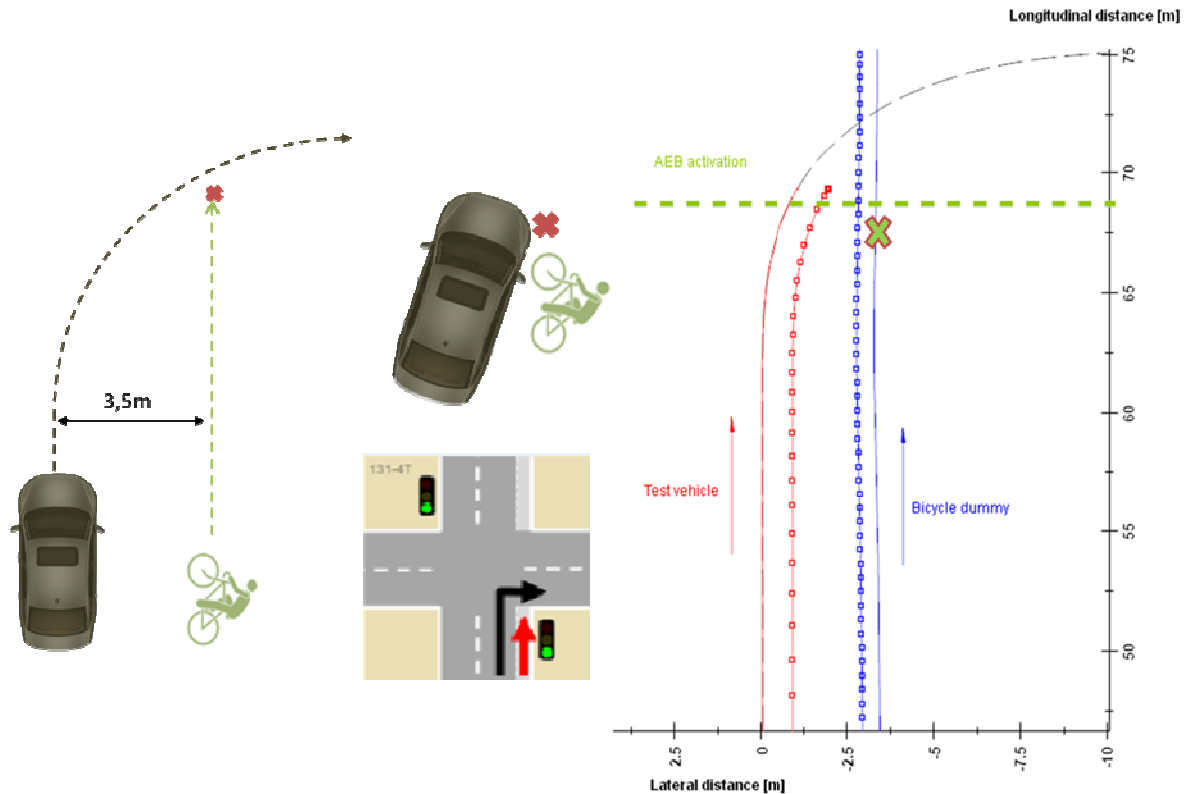
The Euro NCAP ‘Test Protocol AEB-VRU systems’ [3] is the reference document mainly used to reproduce the crossing and longitudinal scenarios. The document provides the test tolerances for test velocities, lateral deviations and steering wheel velocities among others that are strictly followed by test laboratories for the evaluation of AEB VRU systems. Both stationary and turning scenarios are not yet part of Euro NCAP test protocols and therefore a PROSPECT test protocol had to be developed. The challenges regarding the derivation of naturalistic trajectories were described above.

## Results

In the following exemplary final test procedures and test results are shown and explained. Since the PROSPECT project was focused on urban intersection scenarios with VRU participation, these scenarios are described in this paper. All results will be publicly available in the corresponding Deliverable later in 2019. As expected, the baseline performance was negligible in the newly addressed scenarios, whereas the prototype systems have shown the improvement towards a reaction in complicated urban accident scenarios impressively.

In Figure 11 the right turn scenario with the bicyclist is coming from behind is shown. This scenario is particularly challenging regarding the available field of view. The prototype vehicle had radar sensor to the back to be able to react properly and in time to this critical situation. The graph in the right of the figure provides an example of one of the right turns at 15 kph with AEB activation at 1.25 s before the collision. The programmed right turning trajectory for the test vehicle is represented by the dashed black line. The trajectory travelled by the Vehicle Under Test (VUT) is represented in red. The green dashed line represents the activation point of the AEB system. Only shortly after triggering the intervention the vehicle come to a complete stop, indicated by the end of the red solid line. The blue line is representing the trajectory of the bicycle dummy, which is displaced 3.5 m to the right of the VUT in this scenario. Both, the vehicle and the dummy, are time synchronized to meet at the calculated impact point and the right front of the vehicle where both trajectories cross. The front wheel of the bicyclist would collide with the front right corner of the vehicle. In the given representation, the solid lines (test vehicle and dummy) are referring to the corresponding GPS measurement point, which is the geometric centre of both bodies. The dotted red line represents the right edge of the vehicle’s body whereas the blue dotted line one is the left edge of the bicyclist dummy. The minimum distance between the vehicle and dummy at the end of the test is 0.82 m. The green X indicates the bicycle position at the moment of the AEB activation. The vehicle cornering speed was varied between 10 and 15 kph, whereas the bicyclist was constantly travelling at 15 kph. The warnings were issued in a range from 1.41 -1.58 s TTC (Time To Collision) and the following AEB intervention was triggered between 1.16 s and 1.32 s TTC.





**Figure 11: Right turning with bicyclist coming from behind.**

In *Figure 12* the right turn scenario with the bicyclist is coming from the far side is shown. For this scenario braking before the turn was introduced. The VUT travels at 30 kph and before turning it decelerates to 20, 15 or 10 kph. The graph in the right of the figure provides an example of one of the right turns at 10 kph with AEB activation at 0.75 s before the collision. The bicyclist is coming from the right side riding next to the road three meters away from the targeted trajectory for the VUT (see *Figure 12*). The impact point for this scenario is the front wheel of the bicycle colliding with the centre of the front bumper of the VUT (50%). The bicyclist was constantly travelling at 15 kph. The AEB intervention was triggered between 0.72 s TTC for lower speeds and a maximum TTC of 2.3 s for higher cornering speed with avoiding all crashes.

In *Figure 13* the left turn scenario with the bicyclist is coming from the near side is shown. The VUT initially travels at 30 kph and before turning it decelerates to 20, 15 or 10 kph. The graph in the right of the figure provides an example of one of the right turns at 10 kph with AEB activation at 0.76 s before the collision. The bicyclist is coming from the left side riding at the road four meters away from the targeted trajectory for the VUT (see *Figure 13*). The impact point for this scenario is the front wheel of the bicycle colliding with the centre of the front bumper of the VUT (50%). The bicyclist was constantly travelling at 15 kph. The AEB intervention was triggered between 0.76 s and 1.06 s TTC avoiding all crashes.



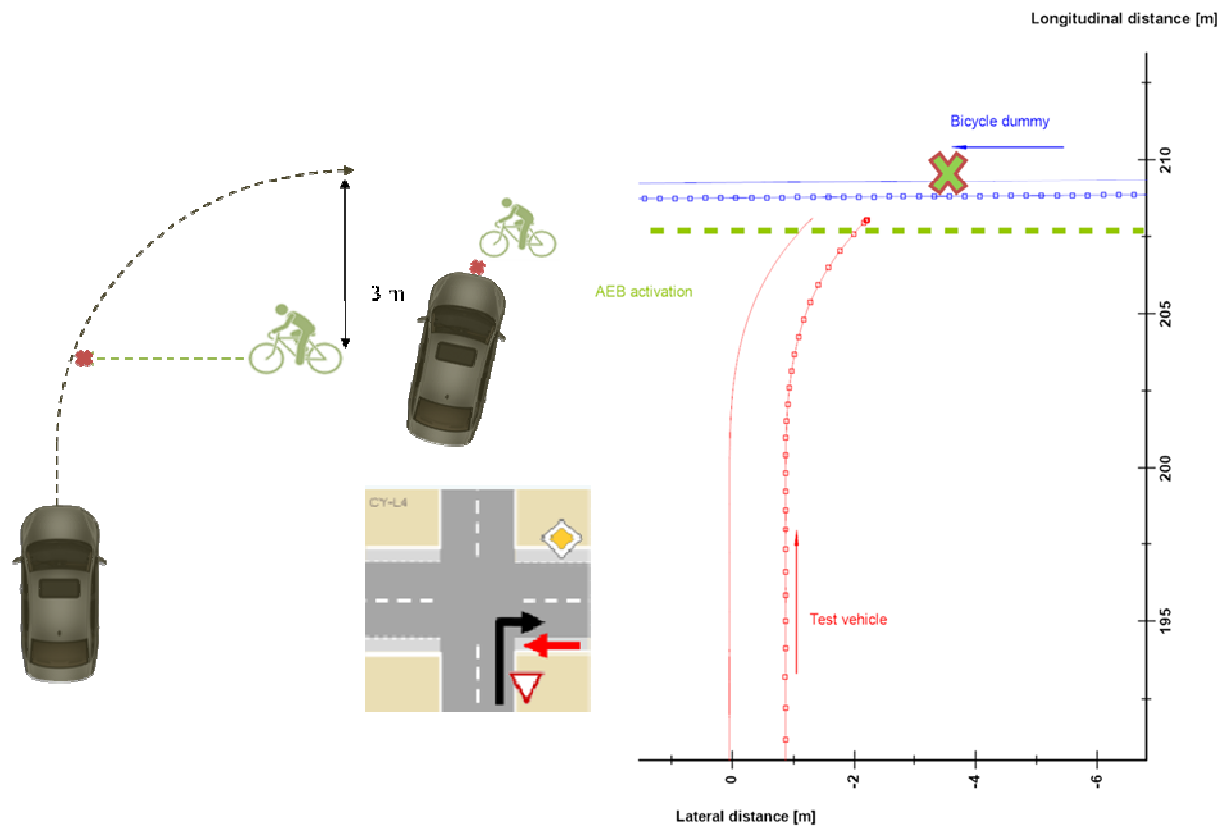


Figure 12: Right turning with bicyclist crossing from the near side.

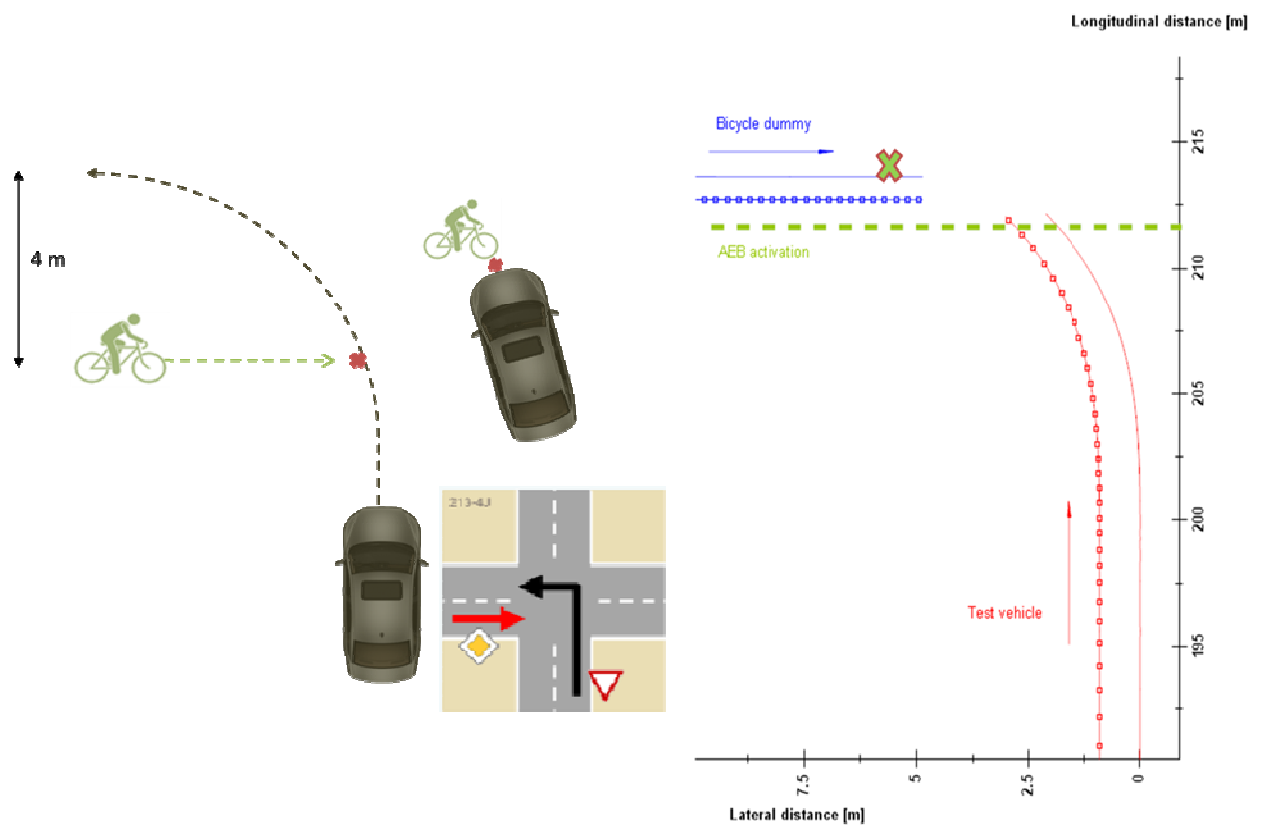


Figure 13: Left turning with bicyclist coming from the far side.

## CONCLUSION

The testing activities have been carried out successfully and have met with the initially described objectives to improving current and developing novel active safety features to prevent accidents involving VRUs like pedestrians and bicyclists. The developed prototypes have performed according to expectations on their assigned test cases avoiding any kind of impact in all the tests. This achievement is mainly due to their advanced processing technology that allows identifying and assessing critical situations involving pedestrians more quickly.

In the roadmap of the European consumer testing agency Euro NCAP 2020 [8] intersection scenarios are planned to become a part of the future protocols. The research in the European funded project PROSPECT provides a first step towards addressing such scenarios in the near future. The findings and the proposed trajectories for negotiating a left and right turn are a solid basis for further research.

Potential is seen in control strategies for driving robots currently used for conducting those test cases. Since this has not been part of the scope yet, control strategies could be optimized for more detailed trajectories beyond the proposed three sections in this paper. In addition to that, the tuning for those driving tasks has to become more sophisticated. The project was focused on slow urban scenarios with a rather tight radius. In the future, interurban scenarios with higher curvatures and speeds might become a research focus. In this case, the trajectories need to be adapted in dependence of the desired speed profile. Apart from naturalistic driving studies in the field, specific studies on the test track could support a deeper insight in how trajectories are chosen depending on the circumstances and surroundings, e.g. obstructed views or the traffic situation.

## ACKNOWLEDGEMENTS

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